C-2

RESEARCH MEMORANDUM

FLIGHT MEASUREMENTS OF THE LOW-SPEED CHARACTERISTICS OF A 35° SWEPT-WING AIRPLANE WITH AREA-SUCTION BOUNDARY-LAYER CONTROL ON THE FLAPS

By Seth B. Anderson and Hervey C. Quigley

Ames Aeronautical Laboratory
Moffett Field, Calif.

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

WASHINGTON

February 3, 1956

NATIONAL ADVISORY COMMITTEE FOR AERONAUTICS

RESEARCH MEMORANDUM

FLIGHT MEASUREMENTS OF THE LOW-SPEED CHARACTERISTICS OF A 35° SWEPT-WING AIRPLANE WITH AREA-SUCTION BOUNDARY-LAYER CONTROL ON THE FLAPS

By Seth B. Anderson and Hervey C. Quigley

SUMMARY

Tests have been conducted to determine the flight characteristics of an F-86A airplane equipped with an area-suction boundary-layer-control system on the flaps, and to investigate the possible operational problems which may arise on a flight installation of boundary-layer control. The effectiveness of the flap was determined in conjunction with the normal slatted leading edge (open and closed) and a modified leading edge incorporating camber and an increased leading-edge radius. Measurements were made of the lift, drag, and, to a limited extent, of the suction requirements. Performance computations were made to show the effect of boundary-layer control on take-off, climb, and landing. The results of the flight tests are compared with those of full-scale wind-tunnel tests of a similar installation on a model incorporating F-86 wing panels and a modified flap.

The results showed that area suction applied to the flap deflected 64° increased lift coefficient by 0.24 (at $\alpha = 11°$) over that obtained with the flap deflected 38° with no suction. Maximum lift was increased from 1.38 for the 38° flap to 1.54 for the 64° suction flap when the slatted leading edge was used. Improvements in performance due to suction were indicated. The flight tests, in general, verified the results of the wind-tunnel tests in regard to the suction flow requirements; however, lower values of flap lift increment were obtained in flight. No detrimental effects due to boundary-layer control were noted on the flying qualities of the airplane. The serviceability of the porous material was considered adequate.

INTRODUCTION

Boundary-layer control as a means of improving lift has been the subject of many studies. Tests (ref. 1) in the Ames 40- by 80-foot wind

[redacted]

tunnel on a 35° sweptback wing model have indicated that large improvements in flap lift increment[1] can be obtained at high flap deflections by applying suction to an area near the leading edge of a flap. It was reported in reference 1 that values of flap lift increment nearly equal to that predicted by potential theory could be attained for flap deflections up to 65°. These relatively large lift increments could be obtained with small flow quantities and at low values of horsepower.

In order to extend the study of boundary-layer control, it was decided to install and flight test an area-suction-type flap on an F-86A airplane. This would serve, in general, to determine what problems might arise on a flight installation of boundary-layer control. In particular, the following items were investigated: (1) the lift increments due to suction on a swept-wing jet aircraft in flight; (2) the effect of the boundary-layer-control installation on the flying qualities and serviceability of the airplane; and (3) the manner in which the pilot makes use of the lift increment due to suction. The area-suction flap was tested with various leading-edge devices on the wing. From the lift and drag data obtained, computations were made of the landing and take-off performance characteristics of the airplane.

The discussion of the results obtained in items (1) and (2) are presented herein. A detailed discussion of the manner in which the pilots made use of boundary-layer control is given in a separate report (ref. 2).

NOTATION

C_L lift coefficient, $\frac{\text{lift}}{qS}$

$C_{L_{max}}$ maximum lift coefficient

C_Q flow coefficient, $\frac{Q}{VS}$

p free-stream static pressure, lb/sq ft

p_d static pressure in duct of flap, lb/sq ft

P pressure coefficient in flap duct, $\frac{p_d - p}{q}$

q free-stream dynamic pressure, lb/sq ft

Q volume rate of air removed through porous surface, based on free-stream density, cu ft/sec

---

[1]The increase in lift due to deflecting the flap at a constant angle of attack.

S	wing area, sq ft
V	free-stream air velocity, ft/sec
α	angle of attack, deg
$\frac{W}{S}$	wing loading, lb/sq ft
δ_f	flap deflection, deg

EQUIPMENT AND TESTS

The installation of the area-suction flap was made on an F-86A-5 airplane. A two-view drawing of the test airplane is shown in figure 1. A photograph showing the airplane with the boundary-layer-control equipment installed is given in figure 2 and pertinent dimensions are presented in table I. Some of the boundary-layer-control equipment was mounted externally to facilitate installation. The external modifications to the airplane consisted of a faired pod enclosing an ejector pump for supplying suction and ducts on the underside of the fuselage for removing air from the flaps (shown in fig. 3).

An ejector pump furnished through the cooperation of Wright Air Development Center was used for the suction source. This pump mounted under the fuselage is shown in figure 4. Air was bled from the last stage of the compressor of the J-47 engine through a pilot-controlled butterfly valve to the primary nozzle of the ejector pump. The weight of the boundary-layer-control equipment for this research-type installation was 105 pounds. Considerable savings in weight should be possible in a production-type installation.

The F-86A slotted flap was modified to a plain type by reworking the nose section and by removing the flap tracks, and mounting external hinge brackets on the under surface of the wing. This mounting allowed flap deflections up to 65°. The portion of the flap located ahead of the spar was used as a duct and is shown in figure 5. A sketch of the flap cross section is given in figure 6. In order to provide for a continuously variable flap deflection, a rubbing-type seal was used between the flap and the fuselage. Boundary-layer air was drawn in through a graded porous material of sintered stainless steel, having the permeability characteristics shown in figure 7. It should be noted that the characteristics shown in figure 7 were not measured but were those specified to the manufacturer and were designed for a uniform inflow velocity of 3.75 feet per second on the basis of pressure-distribution data obtained from the 40- by 80-foot wind-tunnel tests (ref. 1). The chordwise length and placement on the flap of the porous material were estimated also from the wind-tunnel tests. The porous material was formed easily, was readily adaptable to the flap structure, and had a reported tensile strength of approximately 15,000 pounds per square inch.

Standard NACA instruments were used to record airspeed, altitude, acceleration, duct pressures, and angle of attack. Values of airspeed and angle of attack were measured approximately 8 feet ahead of the fuselage nose. Duct pressures in the flap were measured at the midspan station of the flap. The flow quantity drawn through the porous material was measured by calibrated rakes in the ducts. Measurements taken on the ground with a flow meter indicated uniform inflow velocities along the span of the flap.

Tests were conducted at altitudes of 10,000 and 2,000 feet over a speed range of 150 knots to the stall. The tests were conducted at an average wing loading of 45 pounds per square foot except as noted, with the center of gravity at 22.5-percent mean aerodynamic chord. The engine rpm was held fixed for a given series of test runs. For the data presented in this report, an engine rpm of 70 percent was used (approximate rpm used in landing approach). In obtaining the data for the lift curves presented herein, no attempt was made to change the amount of bleed air to the primary nozzle of the ejector pump with airspeed so as to maintain a critical value of C_Q (the value where further increases in C_Q produce little further increase in flap lift, as defined in ref. 1).

For the major portion of the data reported herein, the normal F-86A-5 type slats were used on the wing leading edge. In addition, tests were conducted both with and without a stall-control fence on a cambered leading edge (described in ref. 3).

RESULTS AND DISCUSSION

Airplane With Slatted Leading Edge

Lift.- The lift data are presented in figure 8 for flap deflections of 55° and 64° for the flap-and-gear-down configuration with boundary-layer control on and off. For comparative purposes, data for the 38° plain flap[2] with no suction are shown in figure 8 also. The data in figure 8 indicate an increase in $C_{L_{max}}$ from 1.38 for the 38° flap to 1.54 for

---

[2]The plain flap at a deflection of 38° was used as a basis for assessing the effectiveness of the suction flap since, at this deflection, the flap lift increment and lift curves were similar to that obtained with the normal 38° slotted flap on the unmodified airplane (ref. 3). The lift curves from reference 3 were not used directly, since drag data used for performance computations reported herein were not available from reference 3.

the 64° flap with suction. A comparison of the lift increment of the 64° flap deflection (suction on) with the 38° flap at a constant angle of attack of 11° (average angle of attack used in landing approach) indicates that approximately 0.24 increase in C_L is realized. It will be noted that some of the increase in lift (0.08) was due to the increased deflection of the plain flap itself (i.e., suction off). The increment in C_L (0.16) due to suction was essentially the same for the 55° flap deflection as for the 64° deflection. The lift increment due to suction was essentially constant over the angle-of-attack range except near $C_{L_{max}}$ where there was a 50-percent reduction. No marked loss in suction lift increment occurred at $\alpha = 6^{\circ}$ as in the tunnel tests (fig. 20 of ref. 1). In the tunnel, this loss in lift was felt to be due to a vortex emanating from the inboard end of the slat flowing over the flap and causing an area of separated flow over a portion of the flap. In the flight tests, the duct structure at the wing-fuselage juncture caused flow separation on the inboard end of the flap and the addition of the vortex flow from the inboard edge of the slat did not increase the amount of separated area at 6° angle of attack as it did in the tunnel.

Drag.- The drag data in figure 8 indicate an increase in drag with suction on at the lower values of lift and a reduction in drag at the higher values of lift. The increase in drag at low C_L values is believed to be due in part to the distortion from an elliptical span loading resulting from the increased lift over the span of the flap. The reduction in drag with suction on at the higher C_L values results from the action of the suction system in delaying separation.

Suction Requirements

Suction requirements are illustrated by the data presented in figure 9 in terms of flap lift increment, ΔC_L, and flow coefficient. These data indicate that the flap lift increased with flow coefficient up to a value of approximately 0.0005, after which no further increase in flap lift occurred. These data bear out the results of reference 1 regarding the amount of flow coefficient required for the most extensive flow attachment attained. Although data were not obtained at other values of α, results in reference 1 indicate no significant change in the critical value of flow coefficient with angle of attack. A pressure coefficient of -4.0 was necessary to obtain the flow coefficient of 0.0005 at a C_L of 1.0. The variation of flow coefficient and pressure coefficient in the flap duct with C_L and indicated airspeed are shown in figure 10. These data indicate that sufficient flow coefficient and pressure coefficient were used over the speed range of these tests.

Airplane With Suction Flap and Various Leading-Edge Configurations

The lift characteristics of the airplane equipped with various leading-edge devices are summarized in figure 11 for a flap deflection of 55°. These data indicate that the type of leading-edge configuration had no effect on the magnitude of the lift increment due to suction in the landing approach ($\alpha = 11^\circ$). There was, however, a difference in magnitude at $C_{L_{max}}$ which was associated with the type of leading edge used. For the type of leading edge which produced a well-rounded lift-curve top and a satisfactory stall such as the cambered leading edge plus fence, less lift due to suction was realized. This was felt to be due to the increased thickness of the boundary layer flowing over the flap at the higher C_L values. This increased boundary-layer thickness was the result of the action of the fence in tending to produce a stall in the area inboard of the fence.

The significance of the decrease in lift due to suction at $C_{L_{max}}$ compared to that obtained at the approach angle of attack is not definitely known. Evidence is given, however, in the results of reference 2 that greater reductions in approach speed were realized than the reduction in stalling speed alone.

The stalling characteristics of the airplane with the various leading edges are described in reference 2. Briefly, it may be stated that there was no adverse effect on the stall by the addition of suction to the flap. The stalling characteristics were satisfactory with the slatted leading edge and the cambered leading edge plus fence. Without the fence or with the slats closed (sealed) the stall was considered unsatisfactory due to an abrupt roll-off.

Factors Affecting Flap Lift Increment

The variation of flap lift increment with flap deflection is presented in figure 12 for the flight and wind-tunnel tests and compared with theory. The theoretical value was calculated by means of reference 4. The wind-tunnel results of reference 1 have been corrected to a common flap chord and corrected for trim. The flight results are presented for the gear-up condition for comparison with the tunnel model which had no gear. The results in figure 12 indicate that the flight flap lift values are less than the tunnel values for both suction on and off. The reason for this is not completely understood. Some of the differences in flap lift are felt to be associated with the effect of the type of wing-fuselage combination used on the flow at the inboard flap edge. In the tunnel tests a midwing mounting was used in contrast to the low-wing position on the F-86A airplane. The results of unpublished wind-tunnel tests have shown that the condition of the wing-fuselage trailing-edge juncture could influence the flap lift increment. Other tests indicated a reduced flap lift increment when the fuselage boundary layer flowed over the inboard area of the flap. Boundary-layer measurements in flight indicated that the fuselage boundary layer extended almost to the inboard edge of the flap but it was not felt to be the major cause of the reduced flap lift. A limited amount of fairing of the upper wing surface at the wing-fuselage trailing-edge juncture resulted in improvements in lift due to suction - the flap lift values approached 70-percent of theoretical flap effectiveness. A complete refairing into a more ideal streamline shape was not possible due to the presence of the duct underneath the fuselage (fig. 3). Other attempts to increase the flap lift increment, such as a fence on the flap, a seal between the wing and the flap, and turning vanes to redirect higher energy air down over the inboard area of the flap did little or nothing to improve the lift increment due to suction.

Operational Characteristics of Boundary-Layer Control

One of the main points of interest in the use of boundary-layer control is the effect on the performance characteristics of an aircraft. Actual measurements of landing distance, take-off distance, climb, and catapult launching were not made, but by use of the flight measurements of lift, drag (fig. 8), and engine thrust, computations have been made of the various performance items for a range of gross weights and at standard sea-level conditions. The methods used for computing performance are noted in the appendix.

Landing characteristics.- In the evaluation of the landing-approach characteristics reported in reference 2 for the suction flap airplane with the slatted leading edge, it was noted that the Ames pilots limited their approach speed because of minimum positive altitude control or ability to flare, maneuver, or arrest a sink rate. The significance of these foregoing reasons in terms of the aerodynamic factors involved is not completely understood at the present time. From an inspection, however, of the curves of thrust required for level flight versus airspeed (fig. 13), a partial answer in qualitative terms is apparent. It will be noted that the average minimum approach speeds selected by the pilots fall close to the speed for minimum thrust. Maneuvers below this speed, because of the associated drag variation and resultant effect on glide path, are apparently not readily handled by throttle manipulation and therefore the pilot chooses to avoid this region.

It is of interest to note the relationship of the selected approach speeds on the lift curves shown in figure 14. From these results it is apparent that the pilots utilized the increased lift offered by the 64° boundary-layer-control flap to decrease the approach speeds by flying at approximately the same attitude with suction off and on. These approach speeds correspond to 1.15 V_{stall} and 1.11 V_{stall} for suction off and on, respectively.

Based on the foregoing values of approach speed and an assumed touchdown speed of 1.05 V_{stall}, the effect of boundary-layer control on the landing distance over a 50-foot obstacle was computed and is shown in figure 15 for various gross weights. These data indicate that a 14.5-percent reduction in landing distance due to boundary-layer control would be obtained at 64° flap deflection.

Take-off characteristics.- In the computations for take-off and climb, account is taken of the thrust loss incurred as a result of extracting air from the engine compressor. In order to operate the engine within allowable tail-pipe temperature limits with the suction system on, a reduction from 100-percent rpm was necessary for the type of engine tail pipe used in the F-86A airplane. The thrust loss associated with the decreased rpm was approximately 150 pounds. It is assumed that in take-off, the bleed-air valve would be opened only to that amount necessary to reach the C_Q value above which no further increase in flap lift occurred (as shown in fig. 4) in order not to penalize unduly the suction system. With a more efficient pumping system (ejector pump used had an efficiency of approximately 15 percent) or a variable exit area type tail pipe, the thrust loss would be reduced appreciably with a resultant gain in performance with suction on.

Consider first catapult take-off. The following assumptions are used in computing the speed at the end of the catapult run. Lift-off speed is selected as the speed at 0.9 $C_{L_{max}}$ or at the maximum ground attitude. This speed has the additional restriction that the longitudinal acceleration shall be equal to or greater than 0.065g.[3] The results of computations of the take-off speeds at the end of the catapult run as a function of gross weight for various flap deflections with suction on and off are presented in figure 16. Indicated on this figure are the H8 catapult characteristics. The take-off speeds for the 55° and 64° flap-deflection configurations with suction on were based on 0.9 $C_{L_{max}}$; the other configurations were limited in take-off speed by ground attitude to the C_L at $\alpha = 16^\circ$. At 21,000 pounds or greater, the 0.065g acceleration requirement becomes limiting. The data in figure 16 indicate improvements in take-off performance with suction on. By use of the H8 catapult characteristics and the data in figure 16, computations were made of the wind required over the deck as a function of gross weight for the limit pressure of 3500 psi, a reduced pressure of 2950 psi, and the catapult end speed limit. These data are presented in figure 17. It can be noted in this figure

[3]Assumed minimum acceleration value used to assure that the aircraft does not sink after launch.

that when the limit H8 catapult pressure is used, wind is required over the deck only for the very highest gross weights. The data in figure 17 indicate that approximately 6 knots less wind would be required for the flap deflected 64° with suction on, compared to the 38° flap with no suction.

Next with regard to a field take-off, the assumption is made that the airplane accelerates on the ground in a level attitude, and at take-off speed the airplane is rotated to the angle of attack corresponding to $1.2\ V_{stall}$. For the transition distance, it is assumed that the airplane is in a steady rate of climb at the 50-foot-height point. The results of the computations, indicate very little change in take-off performance due to boundary-layer control or change in flap deflection. The effect of boundary-layer control on take-off performance is illustrated in figure 18 for 55° flap deflection. For this case, the gains in take-off performance which would result from the use of boundary-layer control are canceled by the thrust loss associated with the type of pumping system used. The take-off performance could be improved by turning on the boundary-layer control after the airplane has accelerated to the take-off speed.

Climb characteristics.- The rate of climb after a catapult take-off ($1.05\ V_{stall}$) and after wave-off ($1.15\ V_{stall}$) are presented in figure 19. These data indicate less rate of climb with the boundary-layer control on due to the loss in thrust previously mentioned. The rate of climb should be adequate, however, over the gross-weight range covered.

Flying qualities.- Turning the suction off produced a nose-up pitch change which was considered small. No hazardous flight conditions were encountered in simulating loss of suction power at any airspeed. There was no marked change in stick-free stability as a result of the use of boundary-layer control.

Serviceability.- Flight tests conducted in areas of moderate rain showed negligible effect of the rain on either the lift due to suction or the pumping requirements. No clogging of the porous material was evident after approximately 50 hours of flight testing. No particular effort was made to protect the porous area in the hangar. No detrimental effects on engine life due to the use of the air bleed (3 pounds per second average) were noted for approximately 67 hours of flight testing.

CONCLUSIONS

Measurements of the flight characteristics of the F-86A-5 airplane with area-suction boundary-layer control applied to the flaps showed the following:

1. Area suction applied to a flap deflected 64° resulted in an increase in lift of 0.24 (at $\alpha = 11^\circ$) compared to the lift of the flap deflected 38° with no suction. Maximum lift was increased from 1.38 with the 38° flap to 1.54 for the 64° suction flap when the normal slatted leading edge was used.

2. Comparison with theoretical flap effectiveness indicated that 70 percent of the theoretical flap lift increment was obtained at 64° flap deflection.

3. A flow coefficient of 0.0005 was needed to obtain the lift increment for 64° flap deflection.

4. Computed performance gains were noted in catapult take-off and in landing with suction on. No significant reduction in field take-off distance was evident.

5. No detrimental effects due to suction were noted on the flying qualities of the airplane.

6. The serviceability of the porous material was considered adequate.

Ames Aeronautical Laboratory
National Advisory Committee for Aeronautics
Moffett Field, Calif., Nov. 29, 1955

APPENDIX A

METHODS USED FOR PERFORMANCE EVALUATION

The following equations and assumptions were used in computing the performance.

Take-off distance:

$$\text{Ground run} = \frac{WV_{TO}^2}{64.4[T - \mu W - Sq(C_D - \mu C_L)]}, \text{ ft}$$

(from ref. 5, pp. 195-196).

$$\text{Air distance} = \frac{50\ W}{T - D} + \frac{V_{TO}^2}{g\sqrt{2}}, \text{ ft}$$

(ref. 6, p. 51) where take-off velocity

$$V_{TO} = 1.2\ V_{stall}$$

$$= 1.2\left(1.71\sqrt{\frac{W - T\sin\alpha}{C_{L_{max}}}}\right), \text{ ft/sec}$$

and

T = engine thrust

$q = \frac{\rho}{2}(0.7\ V_{TO})^2$

W = gross weight in pounds

α = angle of attack at $C_{L_{max}}$

$\mu = 0.02$

(The assumption is made that steady climb has been reached before attaining the 50-foot height.)

Climb:

$$\text{Rate of climb} = \frac{101.4\ VT_{EX}}{W}, \text{ ft/min}$$

where

T_{EX} = excess thrust at V

Landing distance:

$$\text{Air distance} = \left[\frac{(V_{50}^2 - V_L^2)}{64.4} + 50\right]\frac{L}{D}\text{, ft}$$

$$\text{Ground run} = \frac{V_L^2}{64.4\left[\mu - \left(\frac{D}{L}\right)\right]}\log_e\left(\frac{L}{D}\right)\mu\text{, ft}$$

(ref. 7, p. 312) where V_{50} is pilot's actual approach speed, and the landing velocity,

$$V_L = 1.05\ V_{stall}$$

and

$$\mu = 0.4$$

Catapult end speed:

$$V_{TO} = \sqrt{\frac{295(W - T\sin\alpha_{TO})}{SC_{L_{TO}}}}\text{, knots}$$

where

$$T = \text{thrust at 100-percent rpm}$$

$$C_{L_{TO}} = 0.9\ C_{L_{max}}$$

$$\alpha_{TO} = \alpha \text{ at } C_{L_{TO}}$$

REFERENCES

1. Cook, Woodrow L., Holzhauser, Curt A., and Kelly, Mark W.: The use of Area Suction for the Purpose of Improving Trailing-Edge Flap Effectiveness on a 35° Sweptback Wing. NACA RM A53E06, 1953.

2. Cooper, George E., and Innis, Robert C.: Effect of Area-Suction-Type Boundary-Layer Control on the Landing-Approach Characteristics of a 35° Swept-Wing Fighter. NACA RM A55K14, 1956.

3. Anderson, Seth B., Matteson, Frederick H., and Van Dyke, Rudolph D., Jr.: A Flight Investigation of the Effect of Leading-Edge Camber on the Aerodynamic Characteristics of a Swept-Wing Airplane. NACA RM A52L16a, 1953.

4. DeYoung, John: Theoretical Symmetric Span Loading Due to Flap Deflection for Wings of Arbitrary Plan Form at Subsonic Speeds. NACA Rep. 1071, 1952.

5. Perkins, Courtland D., and Hage, Robert E.: Airplane Performance Stability and Control. John Wiley & Sons, Inc., 1949.

6. Lush, Kenneth J.: Standardization of Take-Off Performance Measurements for Airplanes. Tech. Note R-12, USAF, ARDC, Air Force Flight Test Center, Edwards, Calif., 1954.

7. Dwinnell, James H.: Principles of Aerodynamics. McGraw-Hill Book Co., 1949.

TABLE I.- DIMENSIONS OF TEST AIRPLANE

Wing	
Total area, sq ft	287.9
Span, ft	37.12
Aspect ratio	4.79
Taper ratio	0.51
Mean aerodynamic chord (wing station 98.7 in.), ft	8.1
Dihedral angle, deg	3
Sweepback of 0.25-chord line	35°14'
Geometric twist, deg	2.0
Root airfoil section (normal to 0.25-chord line)	NACA 0012-64 modified
Tip airfoil section (normal to 0.25-chord line)	NACA 0011-64 modified
Wing area affected by flaps, sq ft	116.6
Flap	
Flap area (total), sq ft	23.7
Flap span (from 13.4 to 49.5-percent semispan), ft	7.27
Flap chord (constant), ft	1.67

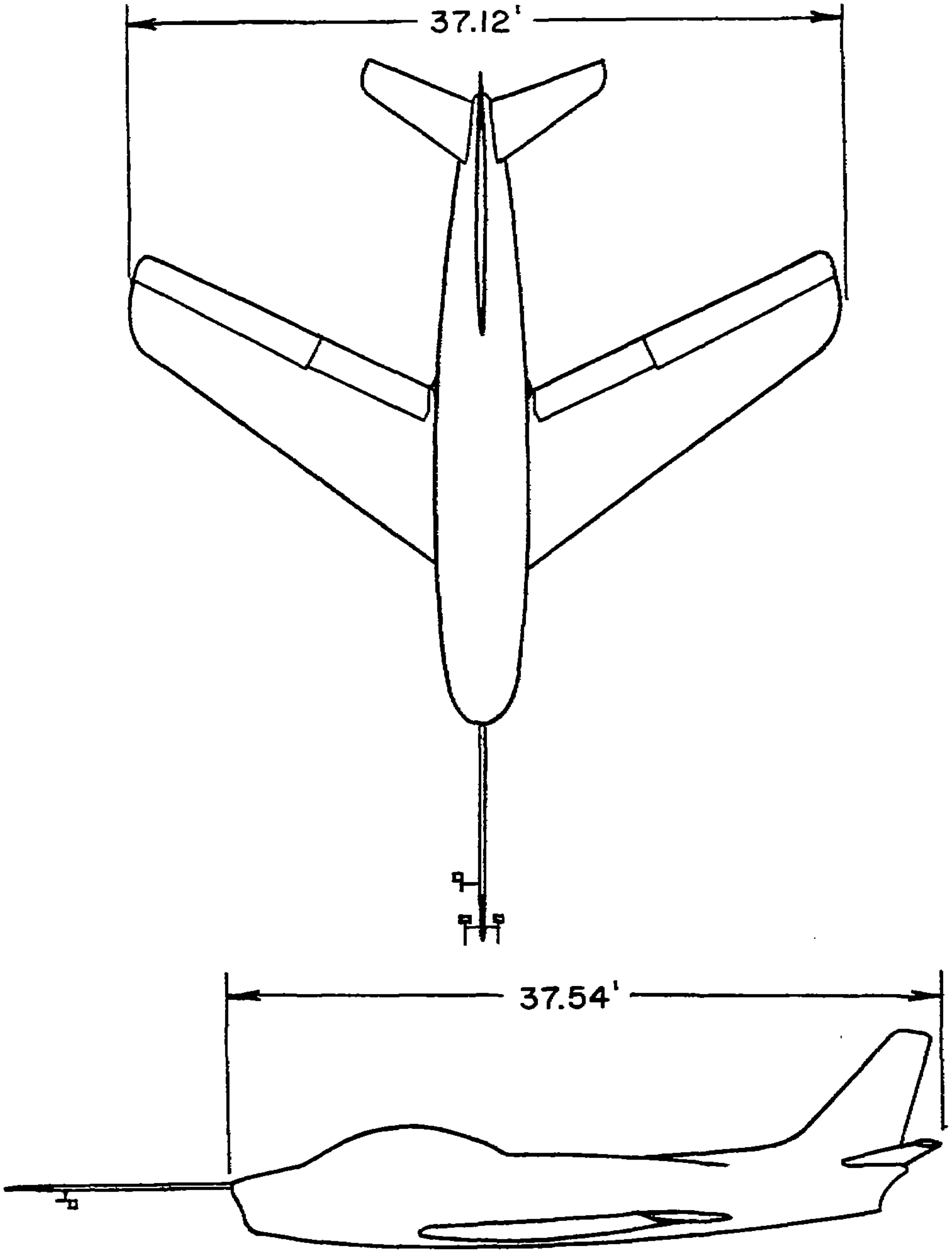
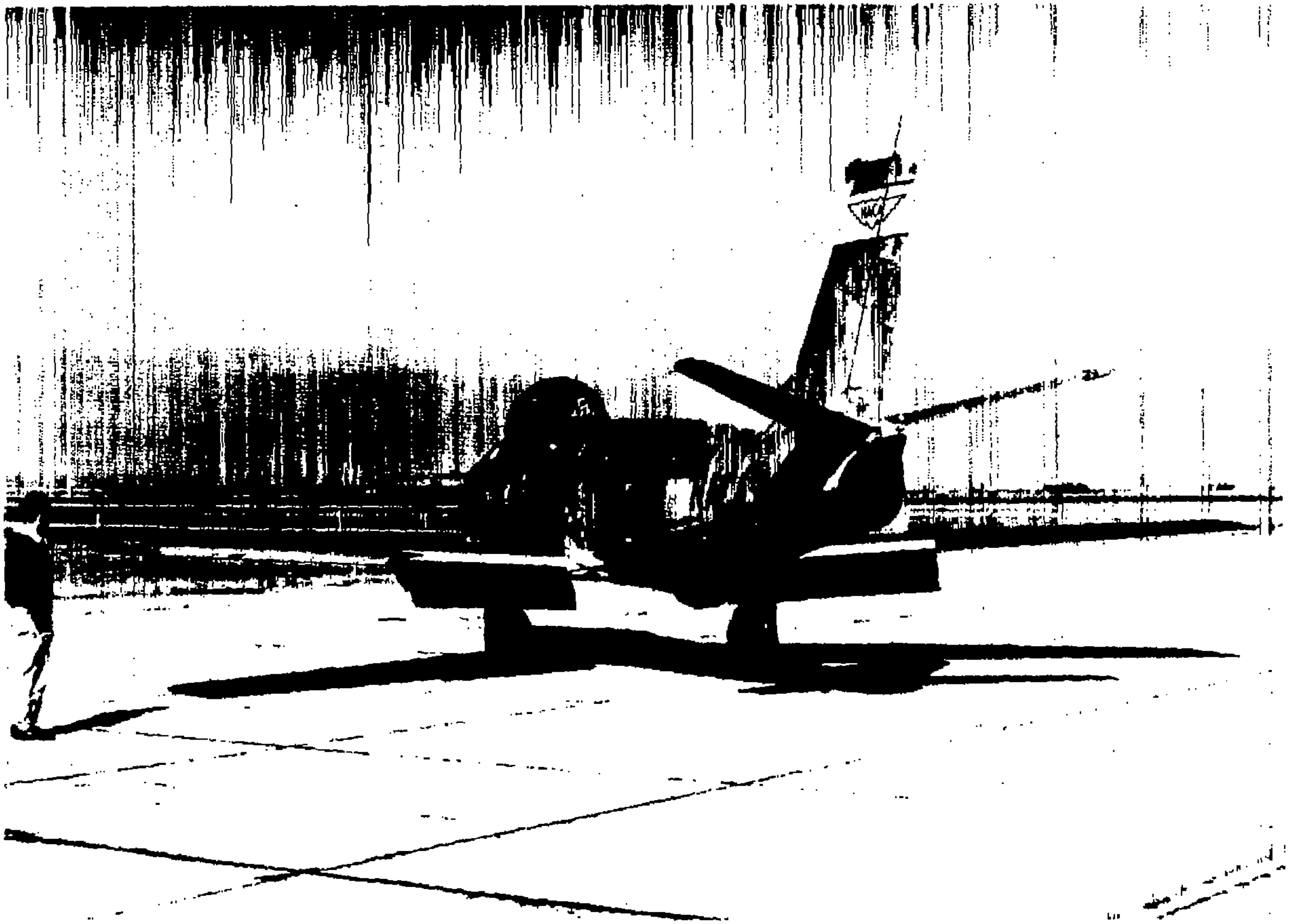


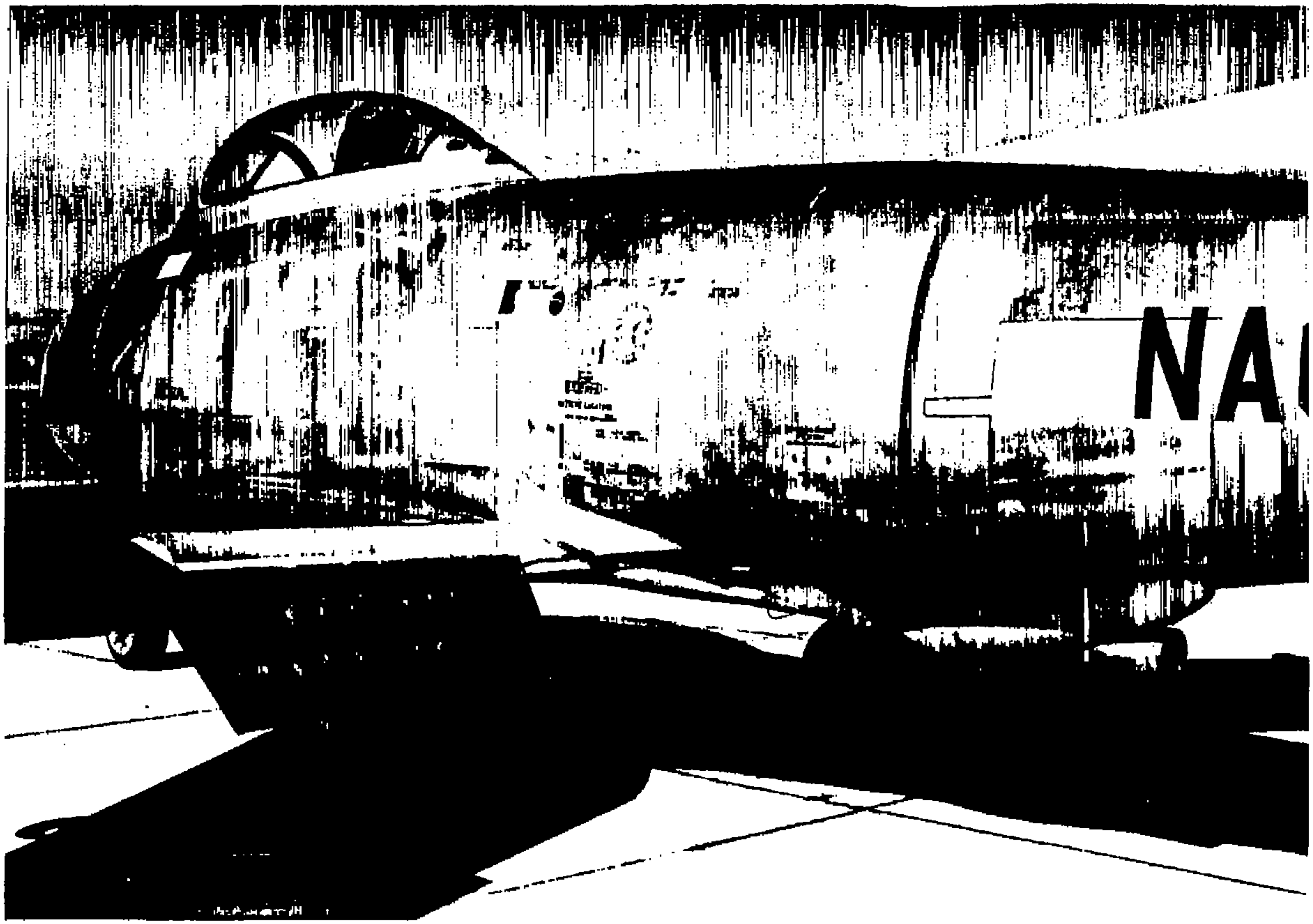
Figure 1.- Two-view drawing of test airplane.

[redacted]



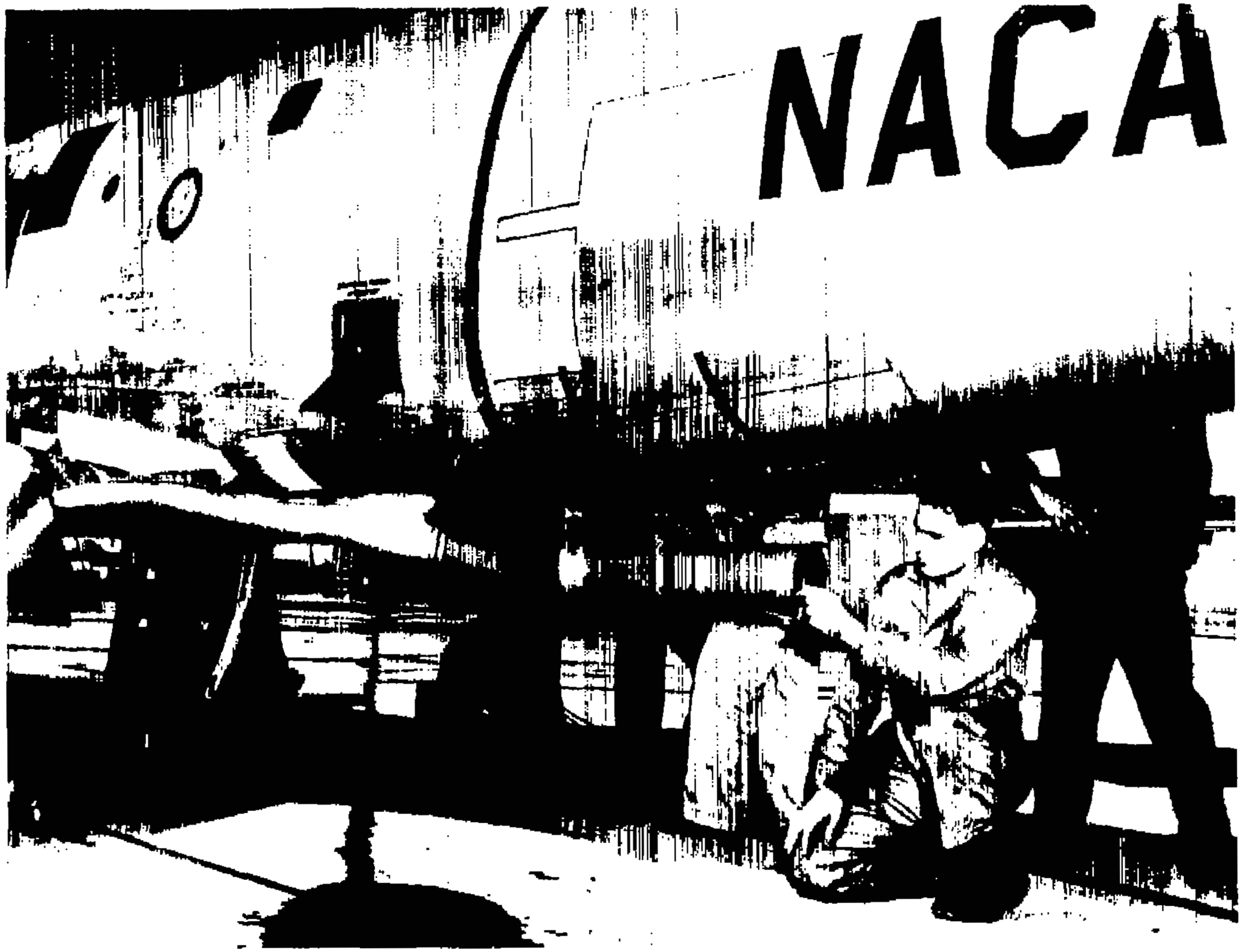
A-20150

Figure 2.- Three-quarter rear view of test airplane with suction flap deflected 55°.



A-20164

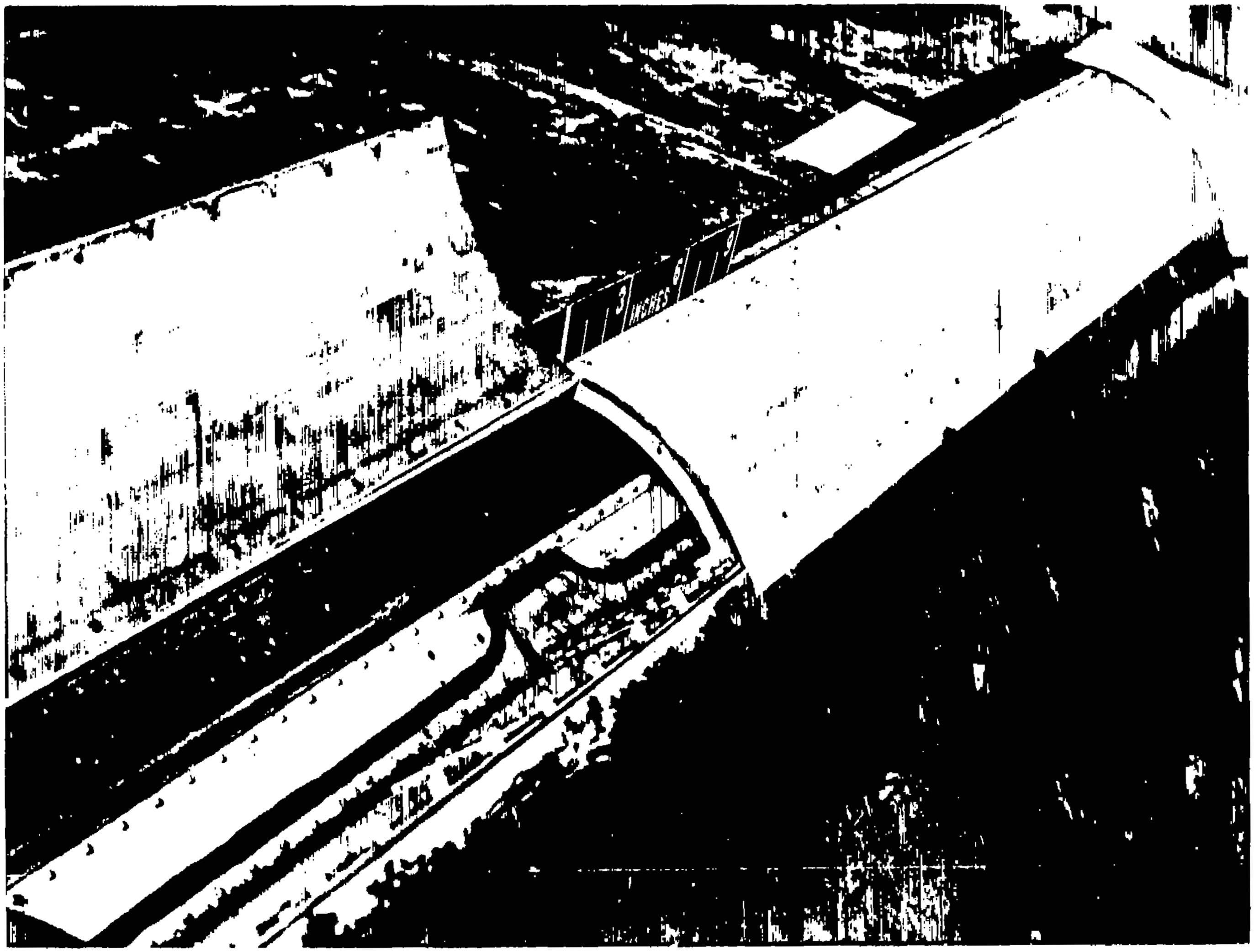
Figure 3.- Close-up showing suction flap, ducts on underside of fuselage, and ejector pump in faired pod.



A-18644

Figure 4.- View of ejector pump on undersurface of fuselage of test airplane.

[redacted]



A-20151

Figure 5.- Close-up showing flap duct and porous material.

[redacted]

[redacted]

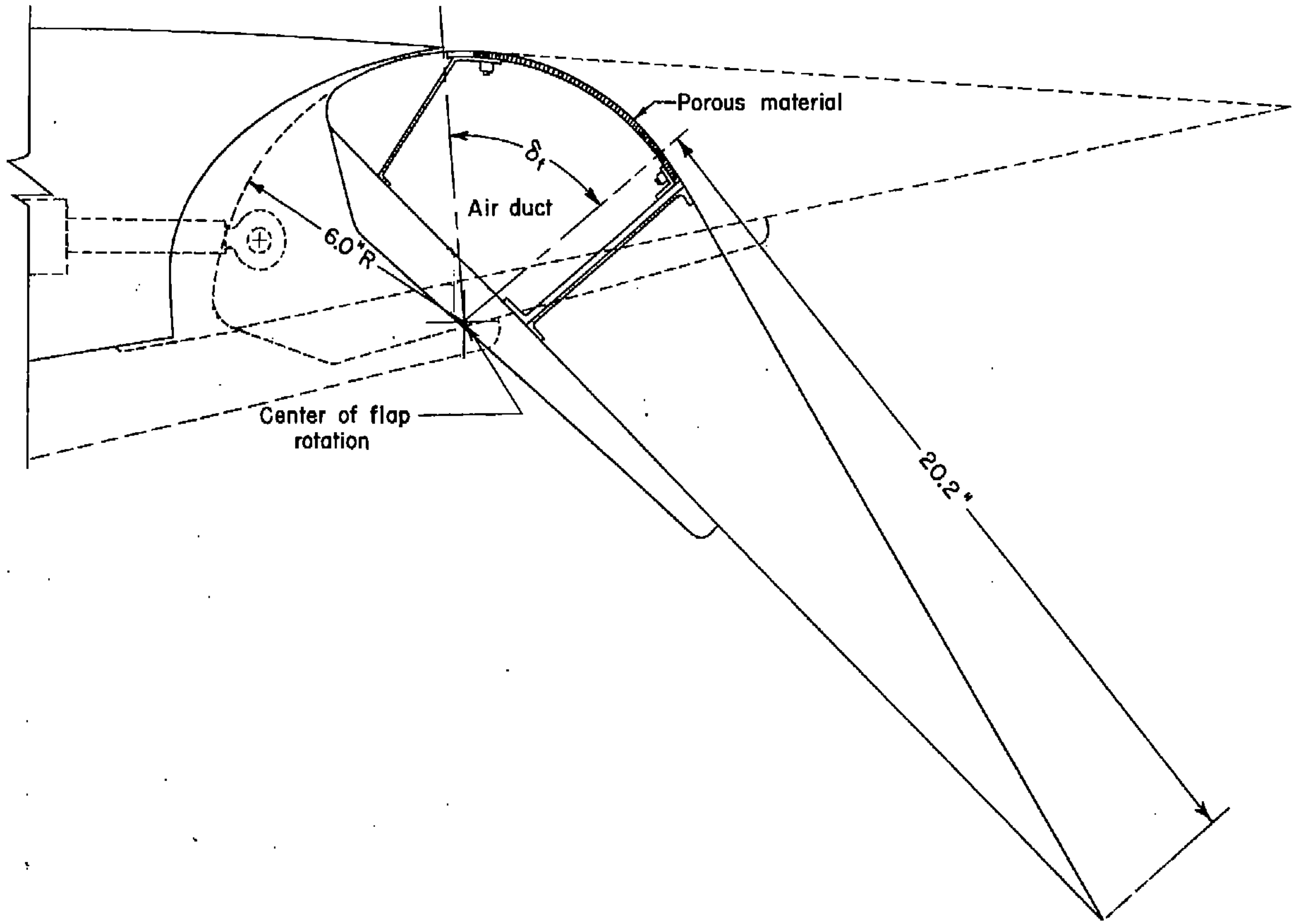


Figure 6.- Cross section of area-suction flap.

[redacted]

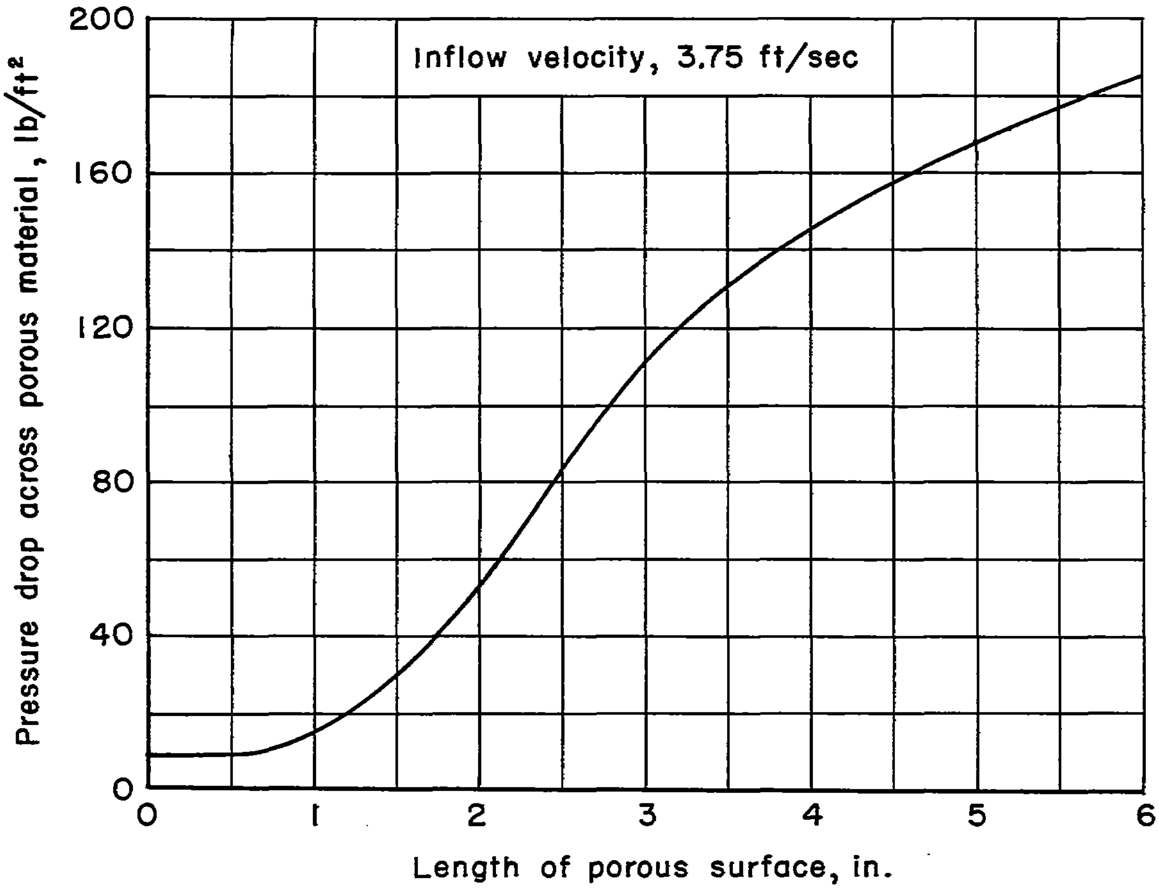


Figure 7.- Variation of pressure drop with chordwise position on flap for porous material.

[redacted]

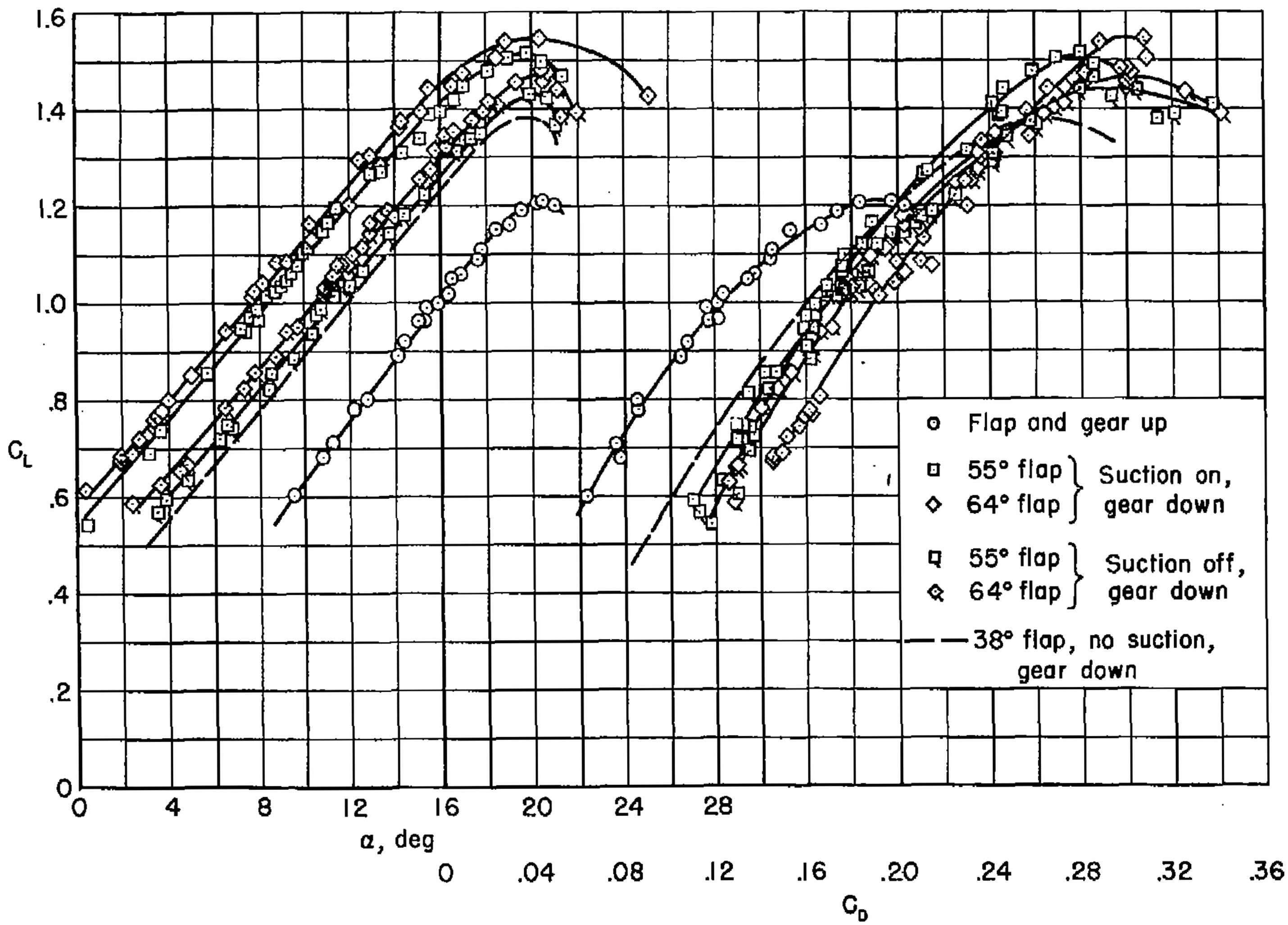


Figure 8.- Lift and drag curves for various flap deflections with boundary-layer control on and off; slatted leading edge.

[redacted]

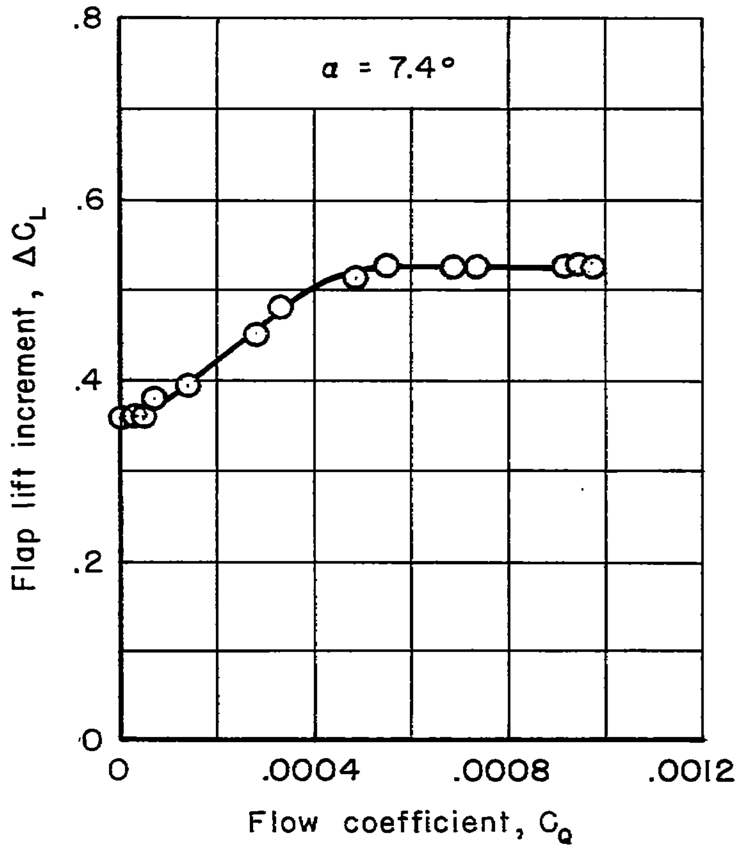
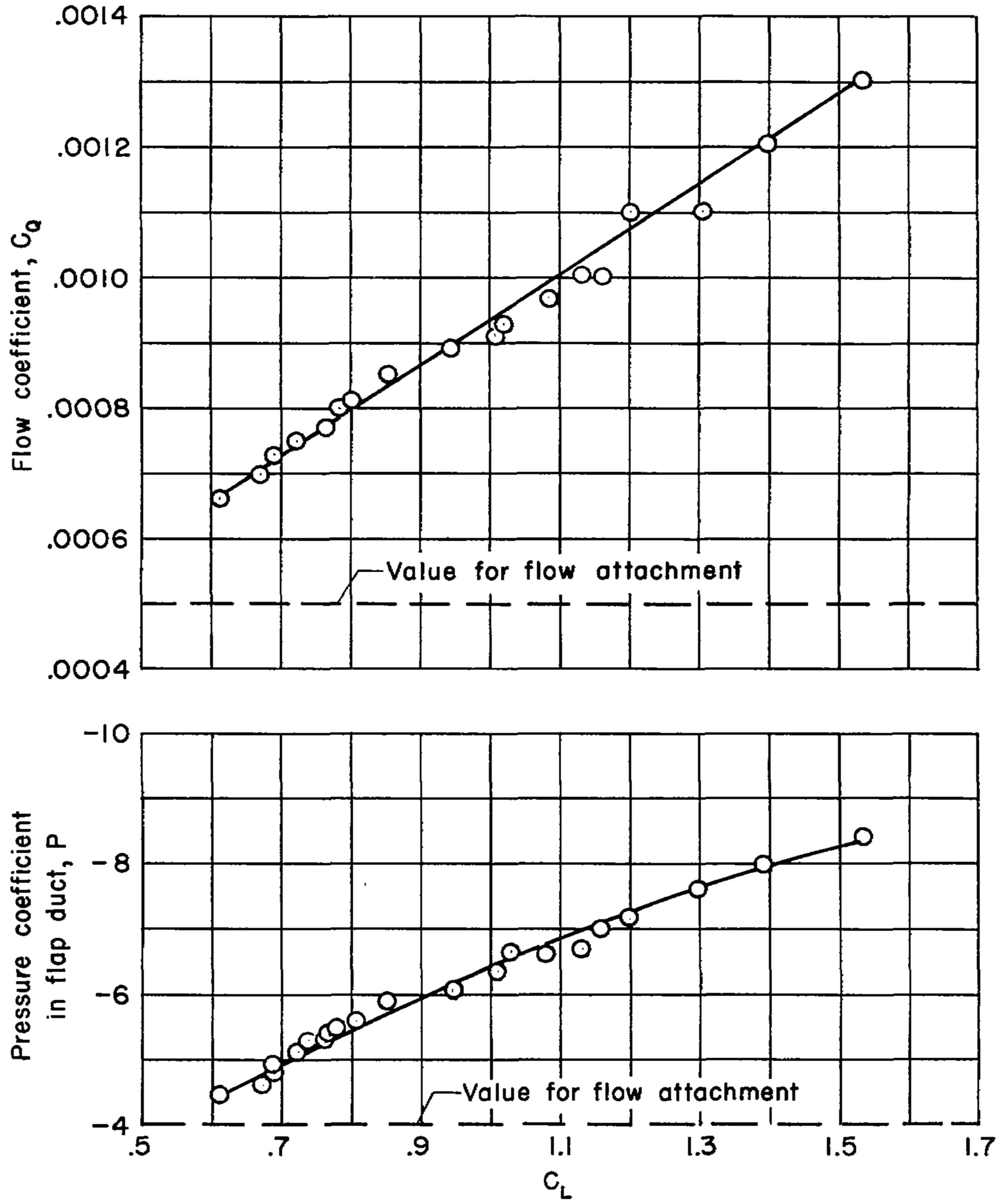
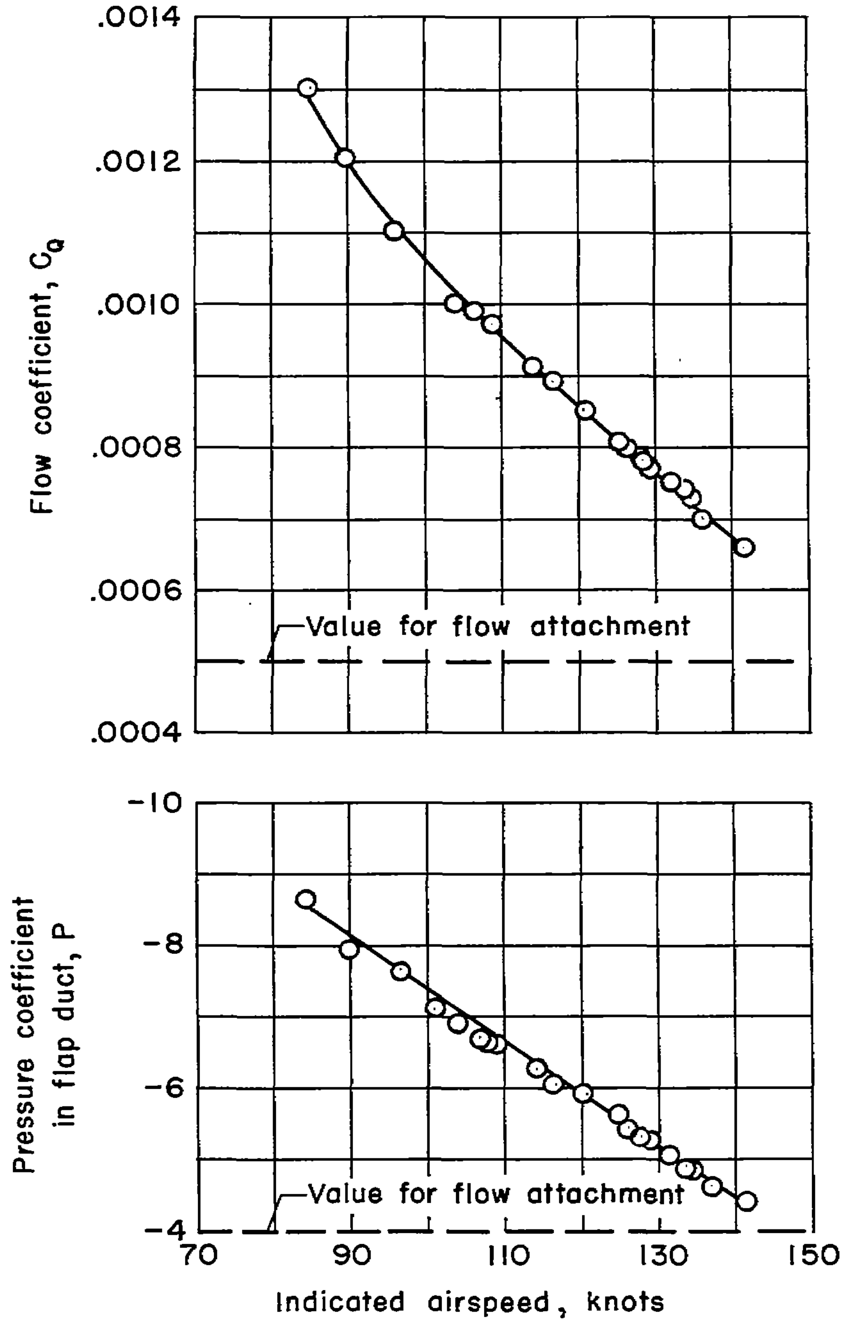


Figure 9.- Variation of flap lift increment with flow coefficient; $\delta_f = 64^\circ$.



(a) Variation of P and C_Q with lift coefficient.

Figure 10.- Pump characteristics obtained over test range with $\delta_f = 64^\circ$; gear down.



(b) Variation of P and C_Q with airspeed.

Figure 10.- Concluded.

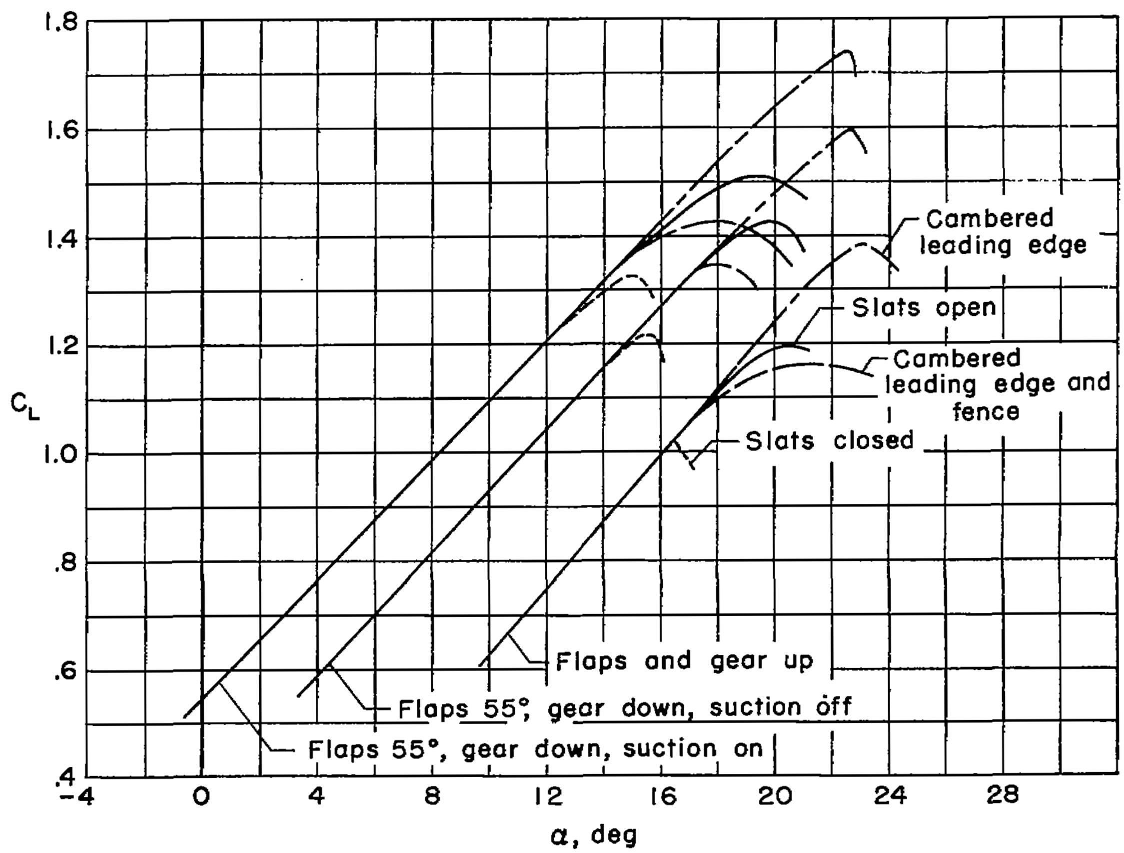


Figure 11.- Lift curves for various leading-edge configurations.

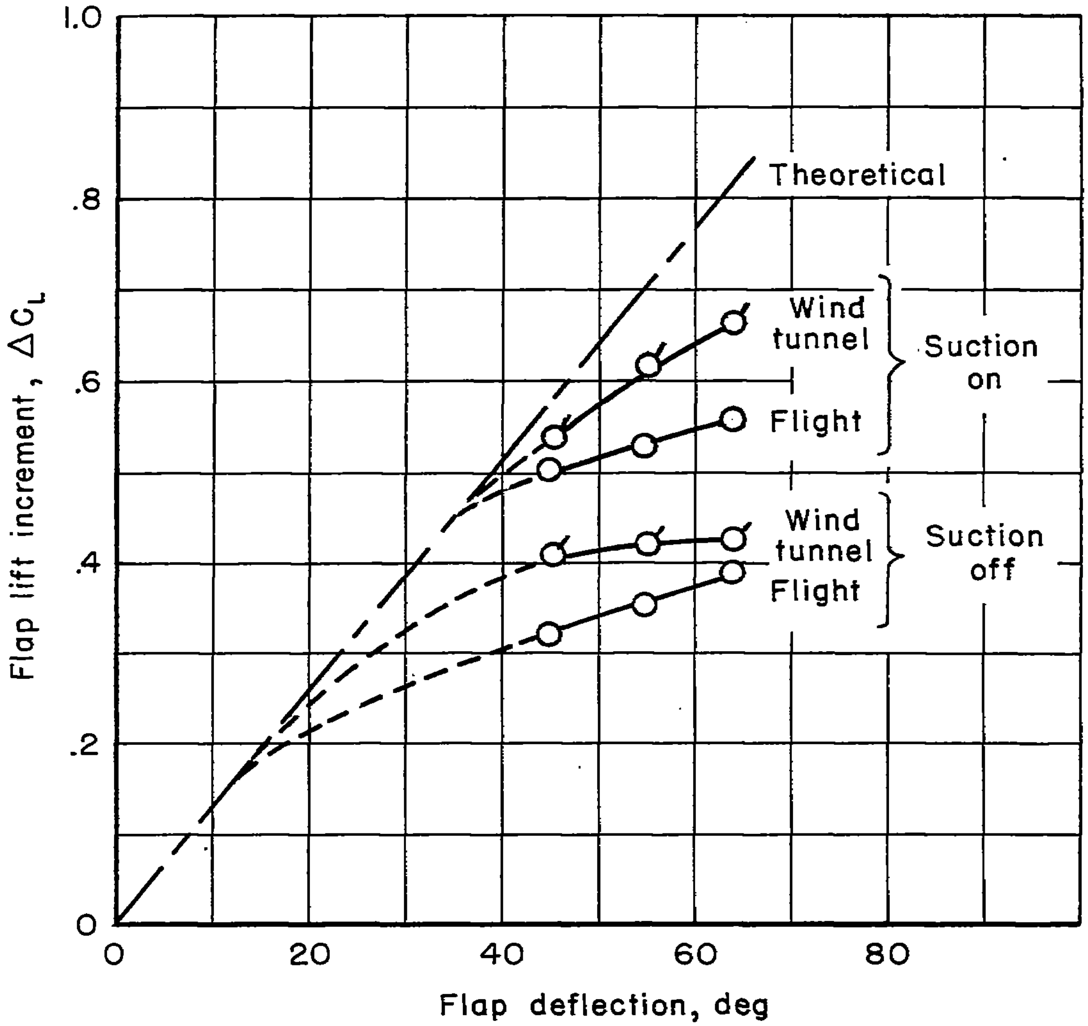
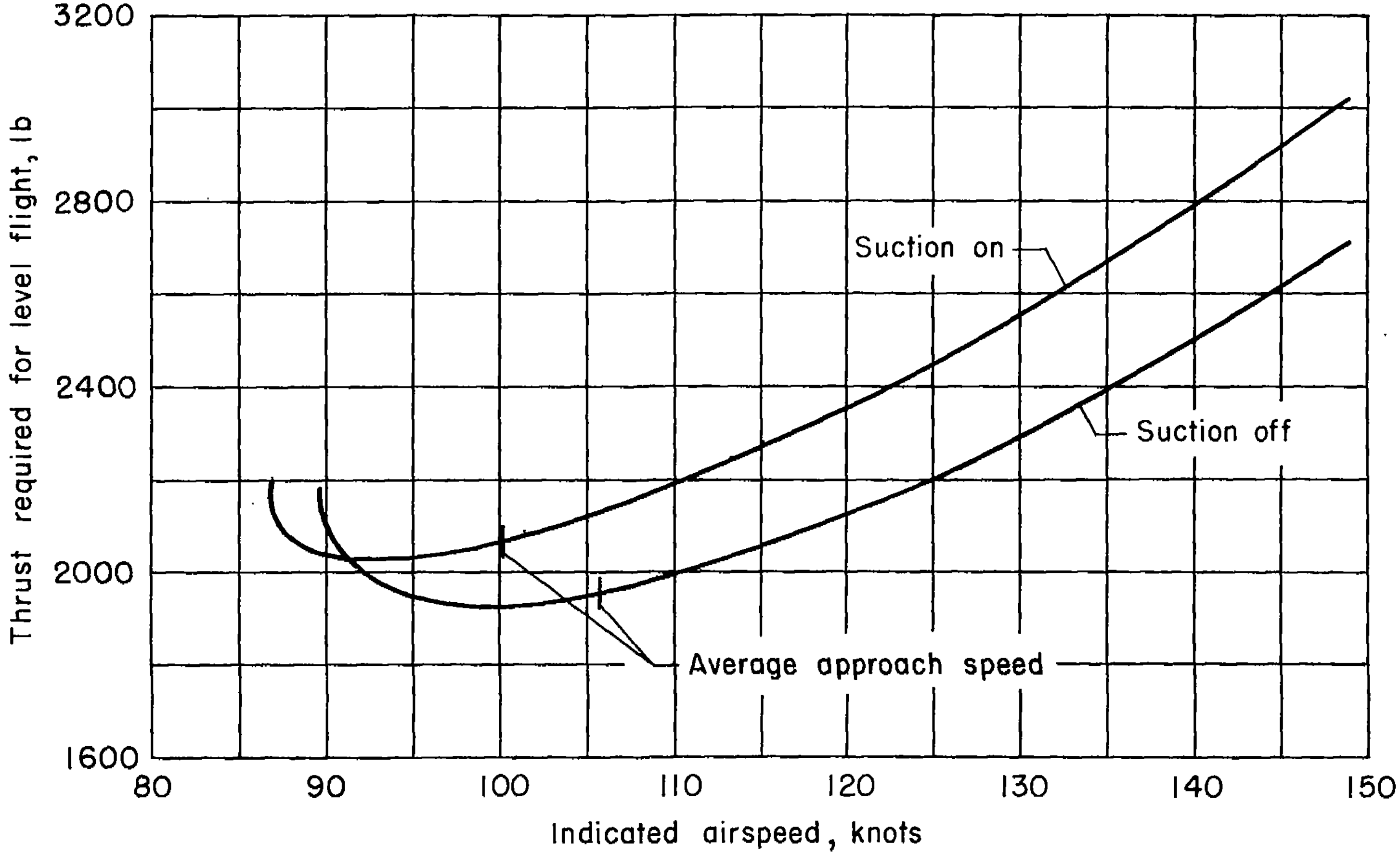


Figure 12.- Comparison of flight and wind-tunnel tests of flap lift increment with flap deflection angle; gear up, $\alpha = 6^{\circ}$.

[redacted]



[redacted]

Figure 13.- Variation of thrust required for level flight with airspeed for 64° flap deflection, gear down, speed brakes extended, slatted leading edge; W/S = 42.5.

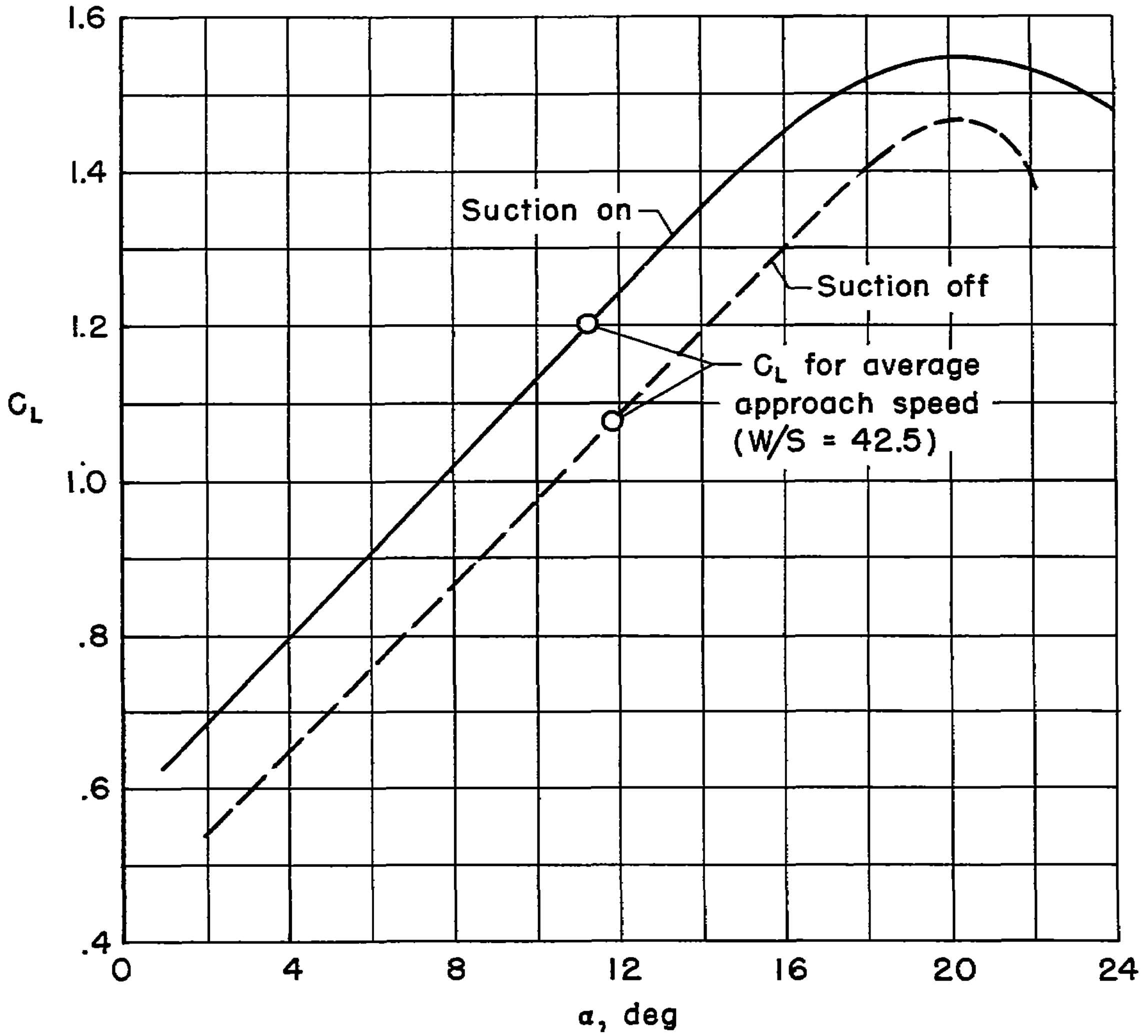


Figure 14.- The relationship of approach speed to the lift curves for suction off and on; slatted leading edge, $\delta_f = 64^\circ$.

[redacted]

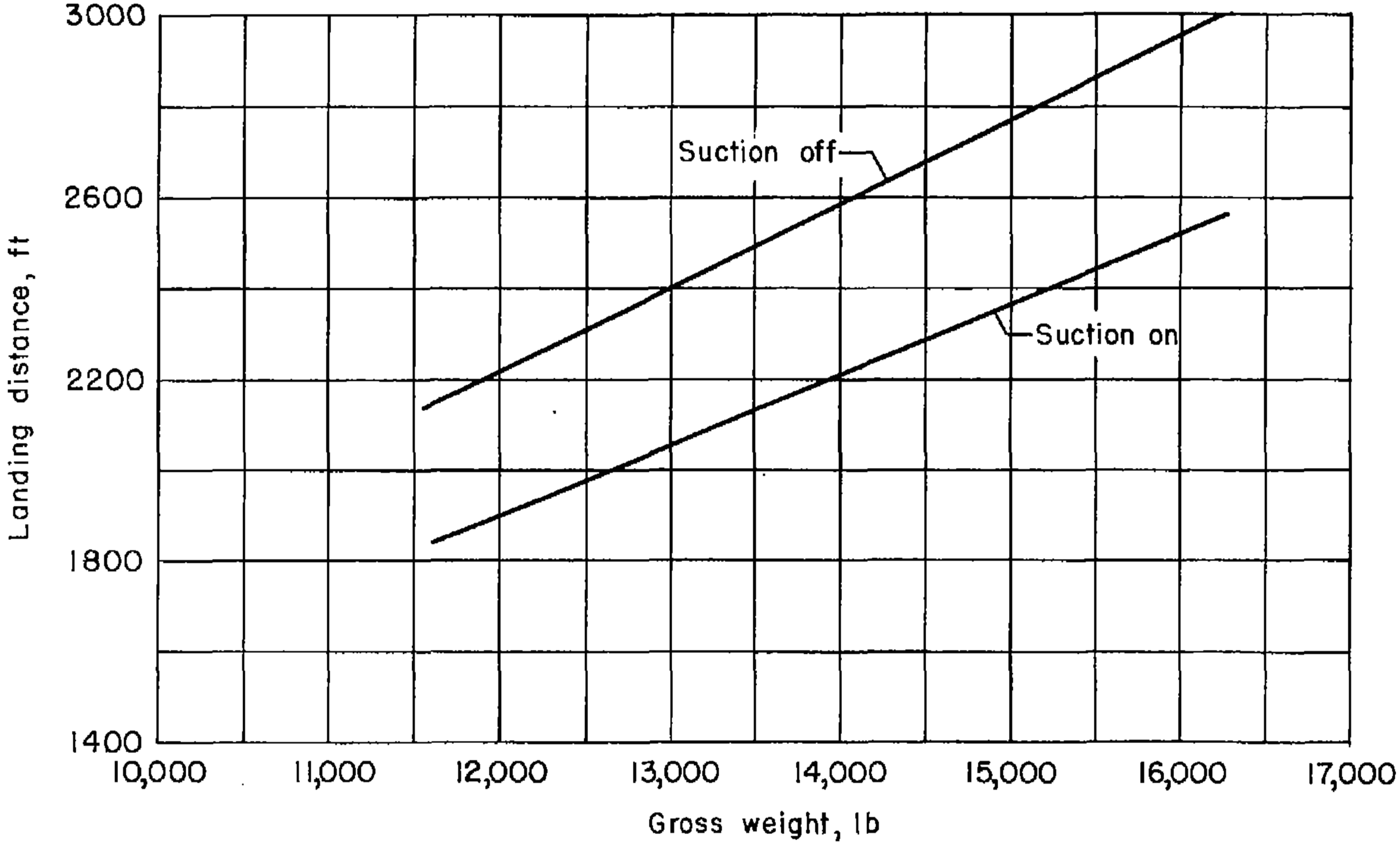


Figure 15.- Variation of landing distance over a 50-foot obstacle with gross weight for 64° flap deflection; speed brakes extended; slatted leading edge.

[redacted]

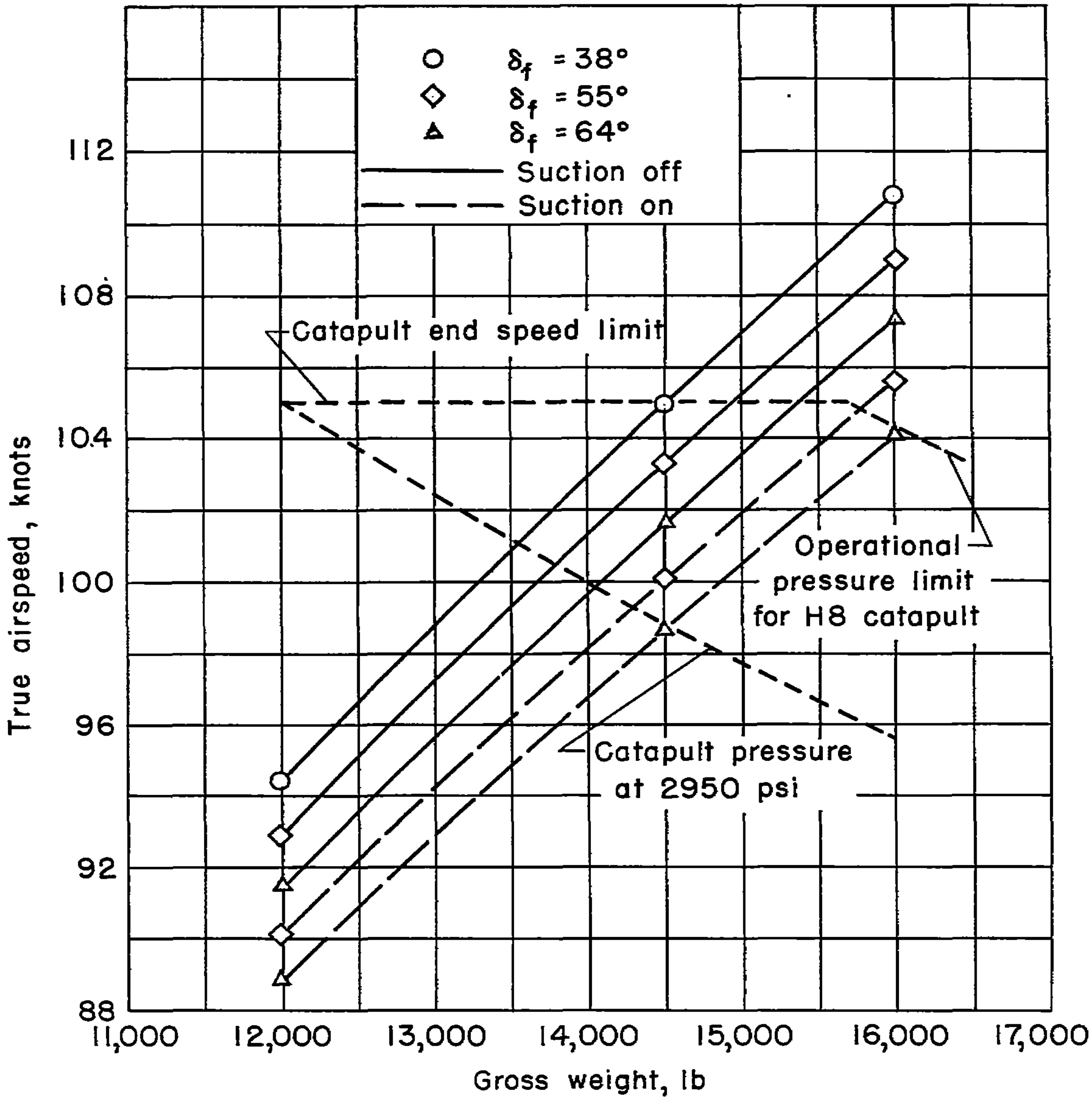


Figure 16.- Variation of catapult take-off velocity with gross weight for various flap deflections with boundary-layer control on and off.

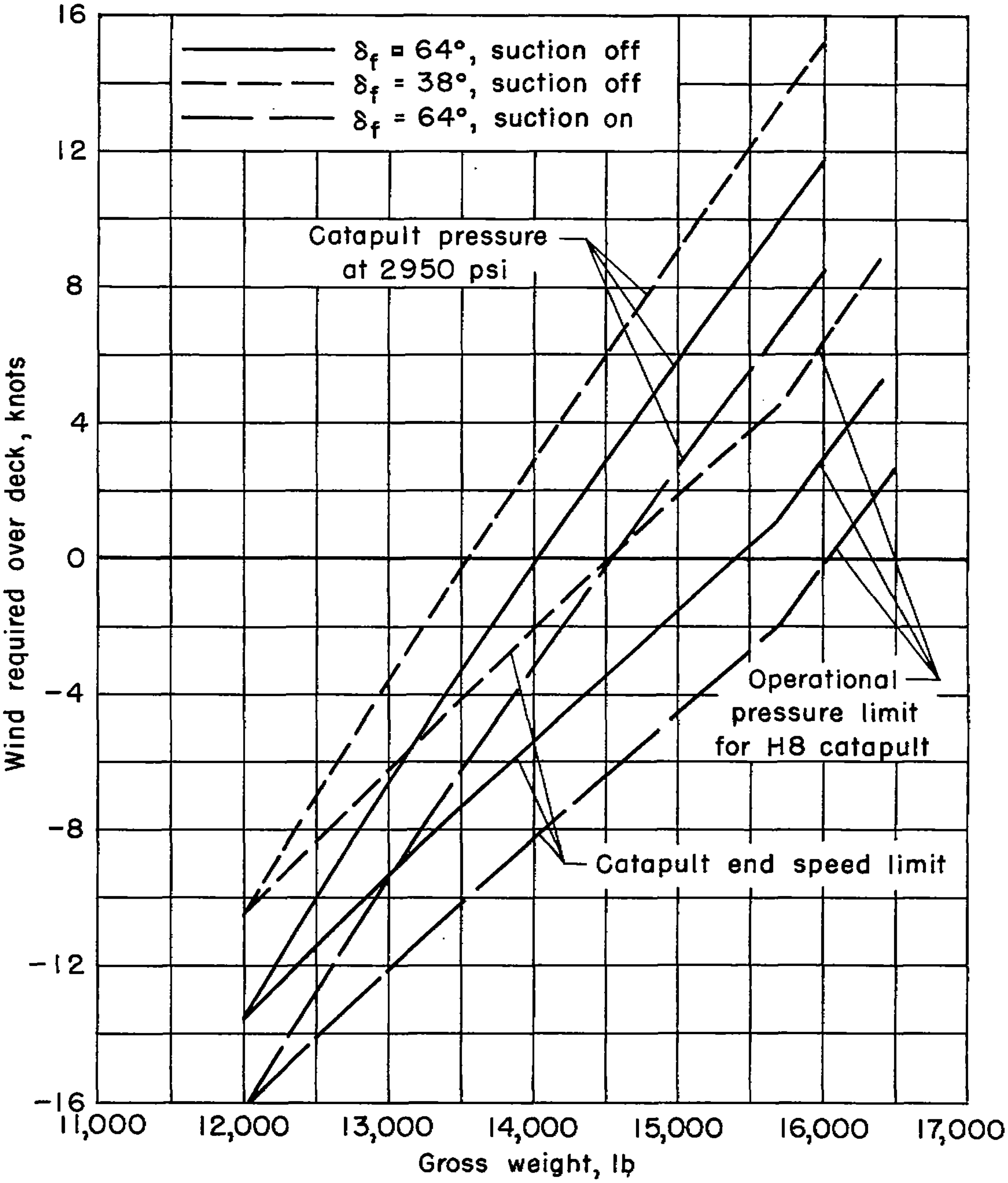


Figure 17.- Variation of wind required over deck with gross weight using the H8 catapult.

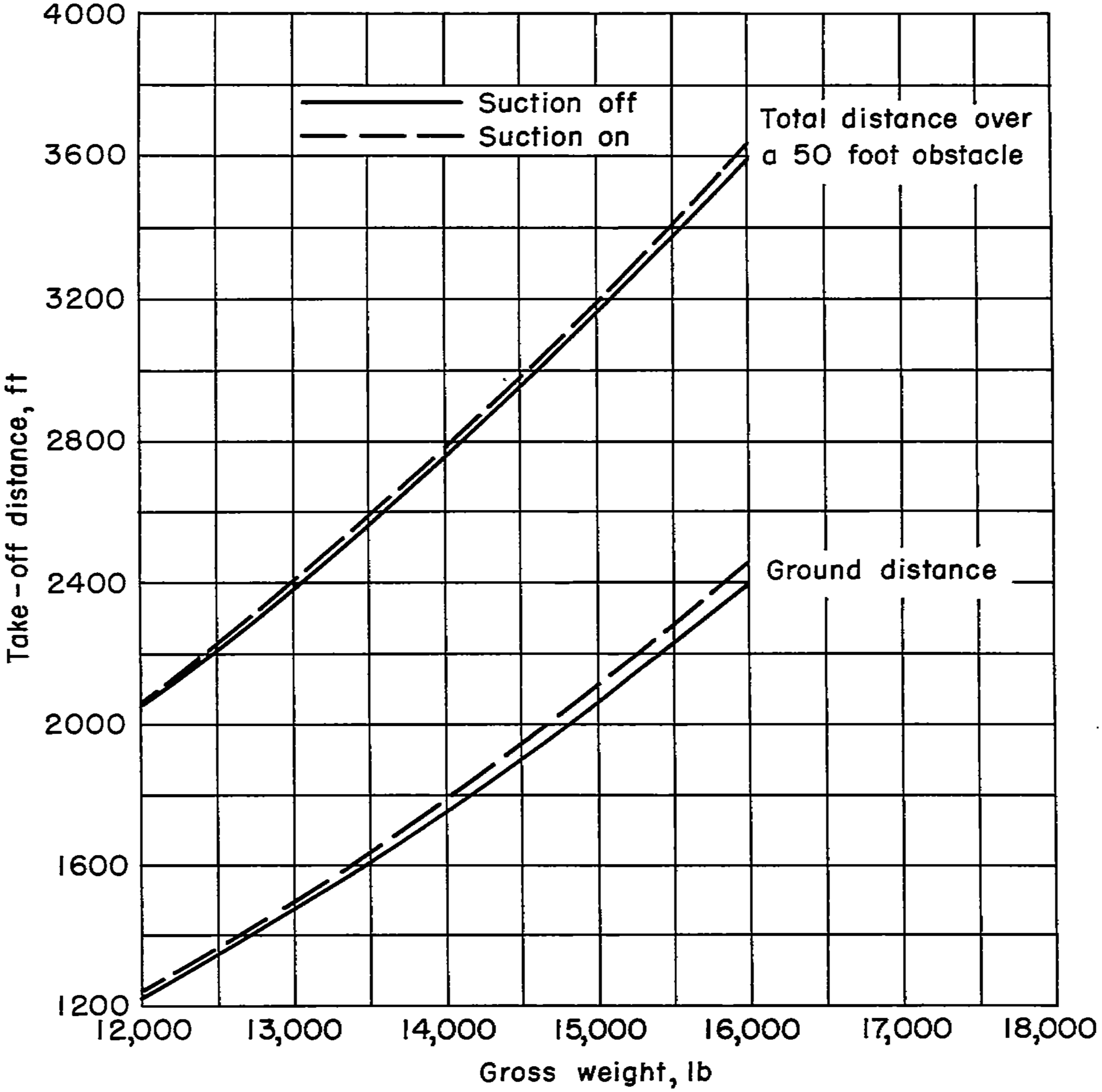
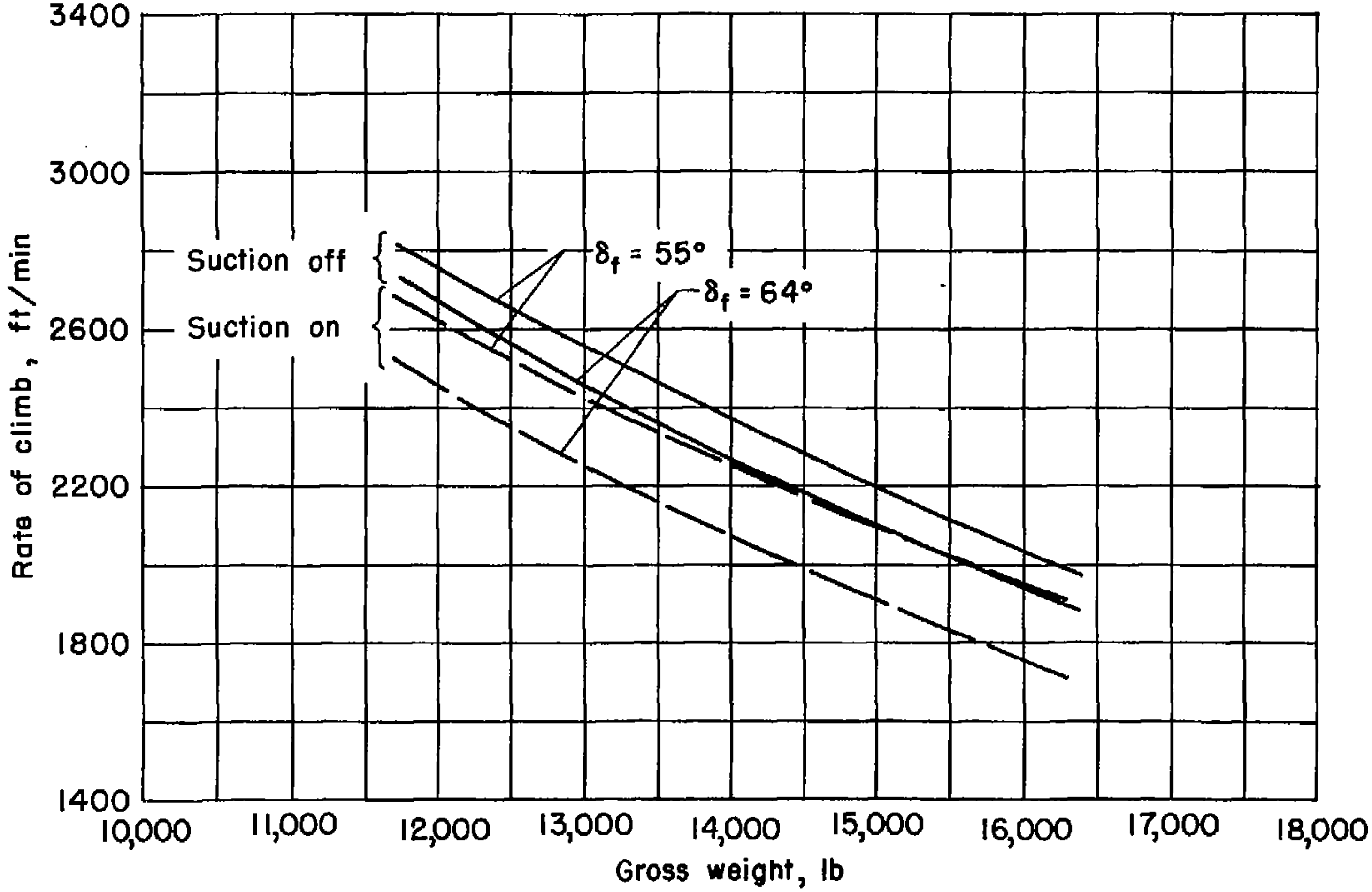
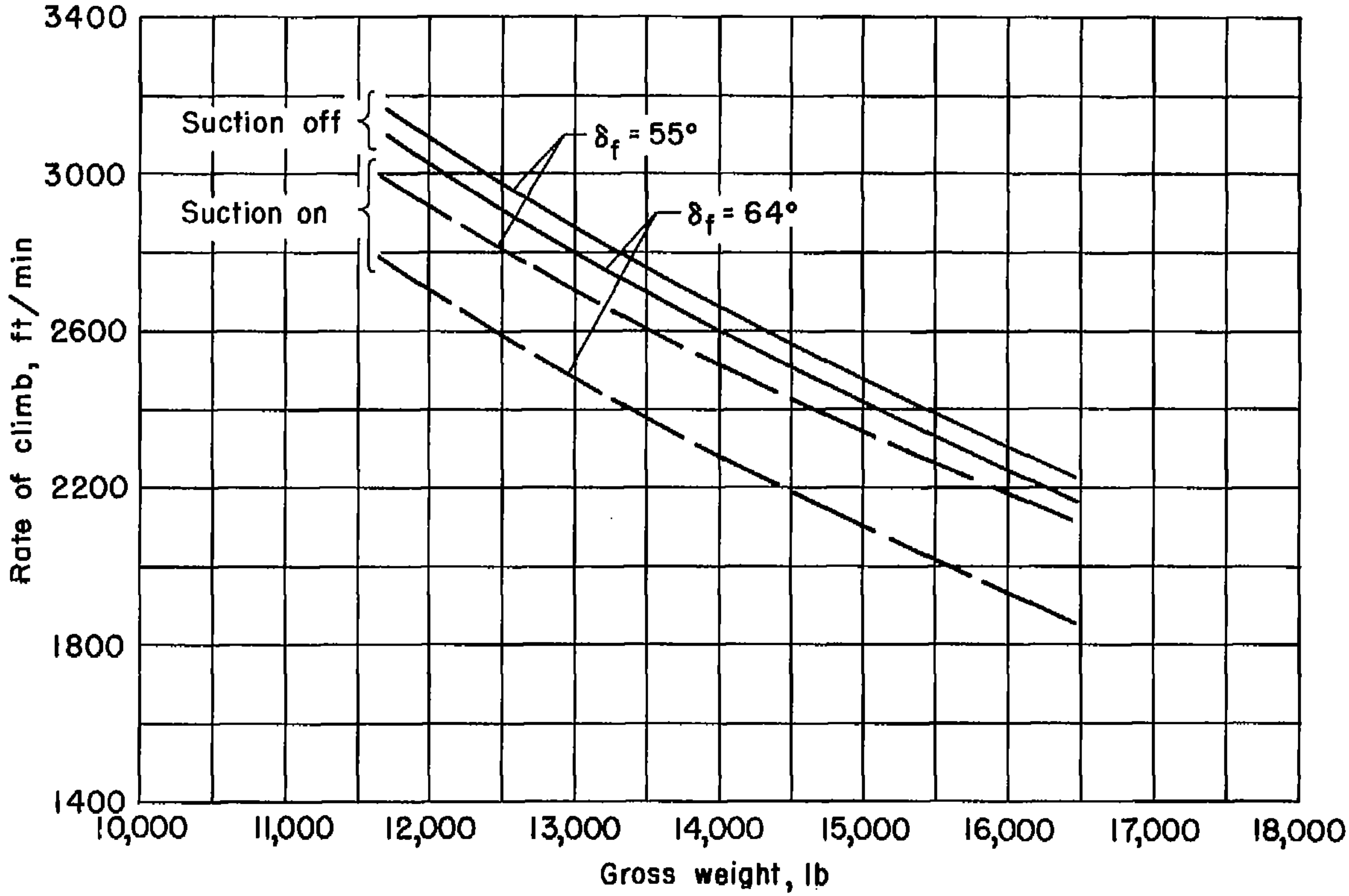


Figure 18.- Effect of gross weight on take-off distance for suction on and off; $\delta_f = 55^\circ$, slatted leading edge.



(a) Catapult speed, $V = 1.05\ V_{stall}$

Figure 19.- Variation of rate of climb with gross weight for various flap deflections with boundary-layer control off and on; slatted leading edge.



(b) Wave-off speed, $V = 1.15\ V_{stall}$

Figure 19.- Concluded.

[redacted]

[redacted]